Net Energy Analysis of Oil Shale Systems

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Introduction

Net energy analyses of three shale-oil-producing systems have been conducted. The presentation of these analyses is divided into several parts. First the methodology is outlined, next process descriptions are given, and after that results are listed and comparisons are made with conventional energy-producing systems. Then a discussion of the results follows, and conclusions are drawn. The final section describes some uses of net energy analysis in decision-making.

Methodology

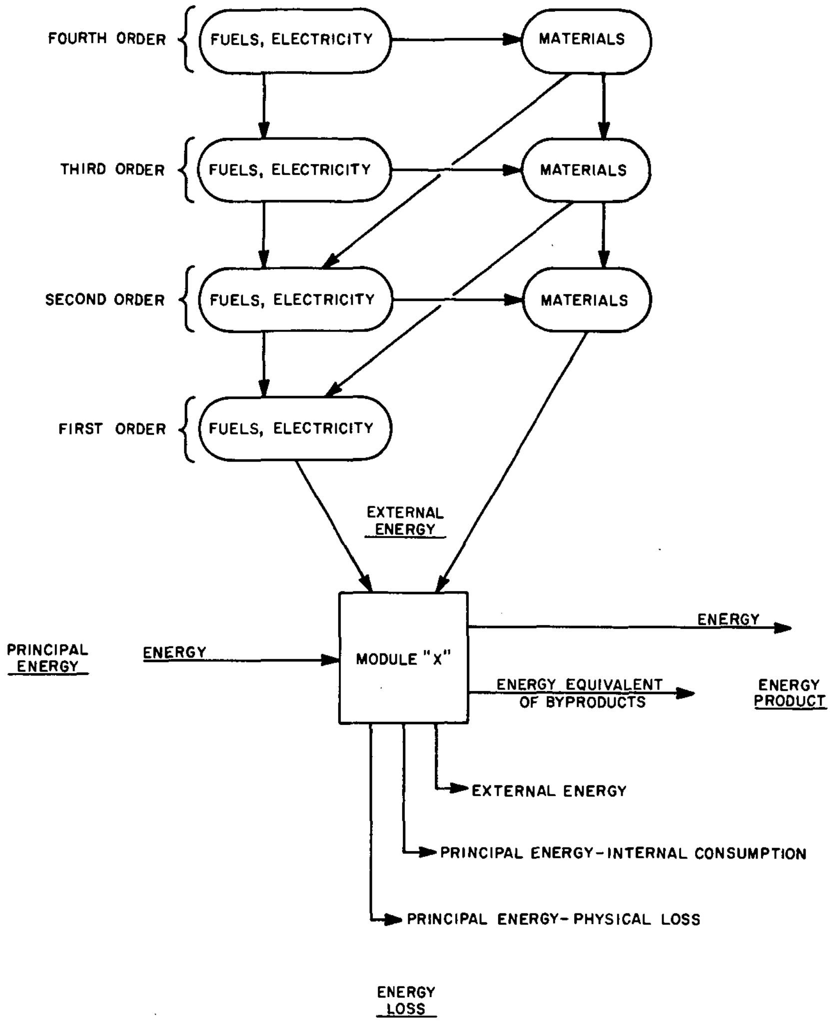
Fuel systems generally can be divided into steps. For the purpose of this analysis seven steps, or modules, were chosen. The seven steps are: (1) Extraction, (2) Transport I, (3) Process, (4) Transport II, (5) Conversion I, (6) Conversion II, and (7) Distribution. All systems follow the same general sequence although there may be minor variations of format from one system to another.

An analysis of a multi-step fuel system reduces to the combination of analyses of individual modules. The diagram of one module of a fuel system (Fig. 1) displays the important features of modular analysis. The first law of thermodynamics is observed--Ein=Eout. Also, energy derived from and used within the system is always internal to the module. These precautions reduce one problem associated with energy analyses, construction of system boundaries.

Energy input consists of two parts, Principal Energy and External Energy. Principal Energy is the primary energy input. External Energy is the sum of fuels, electricity, and of the energy embodied in materials which are purchased or "imported" from energy systems other than the one being analyzed.

The energy "backup" needed to deliver External Energy must be considered to fully account for energy drain from other energy systems. This is diagrammed as ascending higher orders of External Energy. Two different methods have been used to compute the higher-order energy inputs. Conversion factors developed from economic input-output data [1] were applied to material dollar costs, after appropriate deflation to the base year of 1967. This method is the best available for each material input without employing tedious calculations. However, for fuels and electricity the alternative of iteration combined with empirically derived approximations at or above order three is used. This alternative is more precise, and flexible, than the application of conversion factors similar to those used for material energy equivalents.

Energy Product and Energy Loss comprise Eout. Energy Product is defined as the major energy form produced by the module, plus other energy produced for outside distribution, plus the energy equivalent of salable byproducts. Energy Loss has been divided into three parts. Physical Loss is the sum of losses of the Principal


FOURTH ORDER
FUELS, ELECTRICITY
MATERIALS
THIRD ORDER
FUELS, ELECTRICITY
MATERIALS
SECOND ORDER
FUELS, ELECTRICITY
MATERIALS
FIRST ORDER
FUELS, ELECTRICITY
EXTERNAL ENERGY
PRINCIPAL ENERGY
ENERGY
MODULE "X"
ENERGY
ENERGY EQUIVALENT OF BYPRODUCTS
ENERGY PRODUCT
EXTERNAL ENERGY
PRINCIPAL ENERGY-INTERNAL CONSUMPTION
PRINCIPAL ENERGY-PHYSICAL LOSS
ENERGY LOSS

Energy input due to spillage, leakage, disposal of waste materials, etc. Internal Consumption is the energy required from Principal Energy to provide heat or power for the process. The third loss category is External Loss. Normally this is the sum of the external energy inputs. In some circumstances, however, an external energy input will be incorporated in the Energy Product, e.g. additives to petroleum products.

Modules are combined simply by adjusting the Energy Product of one module to equal the Principal Energy of the following module, and so on. This automatically requires a corresponding change in the External Energy, the Energy Loss, and the Principal Energy of the modules in the fuel system. Finally, totals for the fuel system, a sequential combination of seven modules, are: (1) Principal Energy--the initial Principal Energy input to the system, (2) External Energy--the sum of External Energy inputs of each normalized module, (3) Energy Loss--the sum of Energy Loss outputs of each module, and (4) Energy Product--the final Energy Product output plus the sum of byproduct energies of each module.

Process Description

One difficulty with analyses of synthetic fuel processes is the absence of commercial data. In this analysis, the best available data is used. However, information presented here should be viewed as probable, not actual, characterization of oil shale processes.

The three oil shale retorting systems studied are the Bureau of Mines Gas Combustion Retort, the TOSCO II Retort, and the Union B Retort. Because the data for each process are calculated averages, and because it is not realistic to draw fine distinctions among oil shale processes without further information, the results will not be specifically identified with each process. Rather, the letters A, B, and C (not corresponding to the order listed above) will be used to identify results.

Bureau of Mines Gas Combustion Retort

The Bureau of Mines Gas Combustion Retort features direct heating of shale by hot combustion gases from partial burning within the retort. A schematic diagram is shown in figure 2. The flow of shale and gas is countercurrent. Consequently, incoming shale is first preheated and then retorted, while air entering the retort is heated prior to combustion by hot spent shale as it exits.

The Gas Combustion Retort has, from an energy efficiency standpoint, advantages and disadvantages. It makes use of carbon remaining on the spent shale after kerogen is pyrolized, and the sensible heat of both spent shale and combustion gases is well utilized. However, the Fischer Assay oil yields (82-87%) are lower than for other types of retorts; and the Gas Combustion Retort cannot handle finely crushed material without briquetting, which adds to capital and operating costs (and therefore to energy use).

TOSCO II Retort

The TOSCO II Retort (Fig. 2) transfers heat from hot (1200°F) ceramic balls to finely crushed raw oil shale. Sensible heat is recovered from the spent shale (950°F); and the ceramic balls are recycled and heated by gas recovered from the retort, as is the incoming raw shale.

Advantages of the TOSCO II Retort are: high oil and gas yields (as high as 108 percent of Fischer Assay); high-Btu gas, since there is no dilution from combustion within the retort; direct retorting of fine shale, even dust.

Disadvantages are: chemical potential of residual carbon is not recovered; the retort is mechanically complex, with many moving parts; shale must be finely crushed, which adds to processing.

Union B Retort

The Union B Retort (Fig. 2) uses externally heated recycled gas to pyrolize oil shale. The product gas from the retort is split; and one part of the gas is burned to heat the other, which is then returned to the retort. A rock pump is used to move shale from bottom to top of the retort. There is no combustion in the retort. The Union B retort yields up to 100 percent of Fischer Assay and produces a high-Btu gas. It is rather simple mechanically. However, the residual carbon on the spent shale is not utilized; and there is little sensible heat recovery, either.

The fuel systems studied in these analyses produce two different final energy forms--gasoline and electricity. The oil shale gasoline systems produce gasoline from oil shale extracted by underground mining, crushed and retorted aboveground, refined at or near the plant site, pipelined 300 miles, and distributed by truck 70 miles. The transportation mileages and refinery type are characteristic of the Rocky Mountain region. Oil shale electric systems are based on underground extraction, aboveground crushing and retortion, generation at or near the plant site, and 150-mile transmission. Conventional petroleum systems correspond to the oil shale systems in refining, product type, and transport distances.

Results and Discussion

Tables 1 and 2 display results for the net energy analysis of three oil shale systems. It can be seen from Table 1 that (with current technology) more external energy is required to produce 100 energy units of gasoline from oil shale processes than from conventional petroleum systems. Furthermore, the process losses for oil shale are higher than for petroleum. However, the initial recovery of petroleum is low, i.e. unrecovered resource is high; and consequently the sum of losses and unrecovered resource for oil shale is comparable to that for petroleum. Similarly, external losses and process losses for oil shale converted to electricity are higher than for petroleum electricity; but the sums of losses and unrecovered resource are comparable.

The analyses of oil shale systems (and of conventional petroleum) are based on commercial or near-commercial current technology. No attempt has been made to estimate the potential of tertiary oil recovery, of subsequent extraction of shale mine pillars, or of improvements in retorting efficiency. Comparisons incorporating such changes require additional studies.

Three questions which appropriately concern the public and their representatives in business and in government are:

TABLE 1

Net Energy Analysis
Summary of Oil Shale Systems

Product: Gasoline
Final Output: 100

Process	Initial Principal Resource Required	Initial Process Input	Total External Losses	Total Process Losses	Total Losses and Unrecovered Resource
Oil Shale A	320	160	16	84	250
Oil Shale B	330	160	12	80	250
Oil Shale C	310	150	14	76	240
Conventional Petroleum	330	110	10	24	250

TABLE 2

Net Energy Analysis
Summary of Oil Shale Systems

Product: Electricity
Final Output: 100

Process	Initial Principal Resource Required	Initial Process Input	Total External Losses	Total Process Losses	Total Losses and Unrecovered Resource
Oil Shale A	980	490	26	440	940
Oil Shale B	1000	500	16	420	930
Oil Shale C	940	470	21	420	910
Conventional Petroleum	1000	330	10	260	970

How much energy is produced by oil shale systems compared to the amount necessary to operate the system?

How efficient are the processes of oil shale systems?

How well do oil shale systems use natural resources?

These basic questions require many modifications, additions, and explanations to respond fully to all the concerns voiced by interested parties. Nevertheless, they are valid, and can be answered generally in the following ways. First, oil shale systems deliver much more energy than they require from other sources. Gasoline-producing systems provide 6-8 times the amount they use, while shale-electric systems deliver 4-6 times as much energy as they consume. Second, process efficiencies for an oil shale system are typically 50-60%, considerably less than the efficiency of a petroleum system (approximately 80%). Process losses to produce 100 units of output are more than three times as much for shale as for petroleum. Process losses are primarily due to retorting, and at the present time different retorting methods vary little in overall efficiency. Third, oil shale systems make as good use of natural resources as do present-day petroleum systems; but neither oil shale recovery nor petroleum recovery is high; and it appears that efforts more fully to extract our finite fossil fuels are essential.

Conclusion

Net energy analyses offer valuable information on energy-producing systems and can be helpful in focusing attention on concerns about use of finite natural fuel resources. Net energy analysis supplements other planning and decision-making tools - e.g. economic analysis, technical feasibility, environmental study, social impact planning. Potential applications include selection of priorities for research and development, aid to energy policy planning, identification of conservation goals for end use consumption, determination of potential improvements in the energy processing and delivery system, and contribution to decisions about resource management and environmental effects.

One example may illustrate the use of net energy analysis. Suppose that it is necessary to provide space heating on a large scale (perhaps to replace dwindling sources of natural gas). Assume the available resources are oil shale and coal. Either resource may be surface or underground mined. Oil shale may be liquefied or further converted to electricity. Coal may be burned directly for space heating (highly unlikely), liquefied, gasified, burned in a steam-electric power plant, or perhaps converted via magnetohydrodynamics. At end use the fuels may be burned in forced-air or water-radiant systems, while electricity may be used for direct-radiant heating or to power heat pumps. Is there a best option or a best set of options among these many possibilities? Which ones produce least resource impact? Which require least "energy support" from existing energy systems? Which are most process efficient (and thus perhaps least likely to produce unfavorable impacts)? Where can improvements in each system be made, and how large are the potential effects of improvements? These are all questions which can be answered using net energy analysis.

Net energy analysis can be employed at the micro level or at the macro level; i.e. the importance of an analysis may be its detail of an energy system, or the central question may be a large-scale comparison of alternatives. A comprehensive analysis will provide both process specifics and summary aggregations.

Many assumptions concerning energy system processes and resource-related variables largely affect net energy analyses. However, difficulties comparing one analysis with another or applying results to different questions can be overcome if investigators are careful to list their assumptions, to explain their methodologies, and to define their stropes of study. Net energy analysis should be presented so that the reader can determine for himself how appropriate a study is to his needs.

Net energy analysis is a useful tool which can and should be used to aid those involved in questions of energy supply and demand. It does not supplant, but rather supplements, other planning inputs. New problems often require new ways of looking at things. Net energy analysis is one new way of looking at energy supply and demand. It is a good addition to the decision-making process.

1/ Herendeen and Bullard 1974